

*STIMULUS PRESENTATION RATIOS AND THE  
OUTCOMES FOR CORRECT RESPONSES IN  
SIGNAL-DETECTION PROCEDURES*

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Three pigeons were trained to discriminate between two line orientations ( $S_1$  and  $S_2$ ). A left-key peck was correct when  $S_1$  was presented, and a right key-peck was correct when  $S_2$  was presented. In all procedures, correct responses were occasionally reinforced with food paired with the presentation of the magazine light. Incorrect responses produced a blackout. Six detection procedures were used. In the first, the signal presentation ratio was varied across conditions and the reinforcer ratio was allowed to covary. In the second, the signal presentation ratio was held constant at 1:1 and the reinforcer ratio varied across conditions. In the third, the signal presentation ratio was varied across conditions and the reinforcer ratio was held constant at 1:1. In these three procedures, correct responses that were not scheduled for reinforcement were followed by blackout. The remaining three procedures repeated those described above with one procedural change: Nonreinforced but correct trials were followed by the presentation of the magazine light. Birds showed systematic preferences for the key associated with the stimulus presented or reinforced most often. There was no change in the birds' performance over changes in the feedback for nonreinforced but correct responses.

*Key words:* signal detection, response bias, discriminability, stimulus presentation ratio, outcomes, key peck, pigeons

In a typical two-choice detection task, subjects are presented with one of two possible stimuli ( $S_1$  or  $S_2$ ) on each trial. One type of response is occasionally reinforced following  $S_1$  trials (a  $B_1$  response, e.g., a left-key peck) and a different response is reinforced following  $S_2$  trials (a  $B_2$  response; e.g., a right-key peck). Figure 1 shows the four possible stimulus and response combinations. The upper left and lower right cells indicate correct responses ( $B_w$  and  $B_z$ ), and the upper right and lower left cells indicate incorrect responses ( $B_x$  and  $B_y$ ). Subjects usually receive some sort of feedback or reward for their correct responses.

Signal-detection theory attempts to describe choice performance in this task as a function of two independent processes: discriminability and bias. Discriminability focuses on how correctly subjects respond; that is, responding  $B_1$  when  $S_1$  is presented and  $B_2$  when  $S_2$  is presented. Discriminability is influ-

enced by factors such as the physical difference between the two stimuli (e.g., Green & Swets, 1966). Response bias focuses on any preference for one sort of response over another, regardless of whether  $S_1$  or  $S_2$  is presented. It is widely assumed that response bias is influenced by changes in the ratio of reinforcers or payoffs obtained over each type of correct response ( $B_w$  and  $B_z$ ), or when  $S_1$  and  $S_2$  are presented with different frequencies.

Nevin (1969) recognized that the two-choice signal-detection paradigm could be integrated with an operant model of choice behavior. Davison and Tustin (1978) provided the most successful formal theoretical account of signal-detection performance from this perspective by relating the detection task to the generalized matching law. The generalized matching law describes how subjects allocate their behavior over two concurrently available responses, such as pecking the left key and pecking the right key (Baum, 1974). It is expressed by the following equation:

$$\log\left(\frac{B_1}{B_2}\right) = a \log\left(\frac{R_1}{R_2}\right) + \log c, \quad (1)$$

where  $B_1$  and  $B_2$  indicate the total number of each type of response (e.g., left- and right-key pecks, respectively). The generalized match-

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This research was supported by a Fanny Evans Otago postgraduate scholarship, a William Georgetti scholarship, and a BNZ graduate scholarship awarded to Victoria Johnstone, and an Otago University Division of Science Research Grant awarded to Brent Alsop. We also thank Stephen Gallagher and Natasha Bankers.

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		response	
		$B_1$	$B_2$
stimulus	$S_1$	$B_w$	$B_x$
	$S_2$	$B_y$	$B_z$

Fig. 1. The four possible stimulus and response combinations from a typical two-choice detection task. The upper left and lower right cells indicate correct responses ( $B_w$  and  $B_z$ ), and the upper right and lower left cells indicate incorrect responses ( $B_x$  and  $B_y$ ).

ing law states that the ratio of responding is determined by three factors. First, the ratio of reinforcement received on the two keys ( $R_1/R_2$ ) influences behavior allocation on each key. Second, the degree to which the  $B_1/B_2$  ratio is influenced by the reinforcer ratio is represented by the parameter  $a$  in Equation 1 (the sensitivity to the obtained reinforcer ratio). Third, the organism may show a constant preference for one key over another, represented by  $\log c$  (inherent bias).

Davison and Tustin (1978) described signal-detection performance as a function of two matching equations, one describing response allocation when  $S_1$  is presented [ $\log(B_w/B_x)$ ] and the other describing response allocation when  $S_2$  is presented [ $\log(B_y/B_z)$ ]. Davison and Tustin suggested that an additional parameter is required in each matching equation because the subject's behavior would also be influenced by whether it perceived  $S_1$  or  $S_2$  on each trial. This influence added another constant, systematic preference for the "correct" response when either  $S_1$  or  $S_2$  is presented ( $\log d$ ). Davison and Tustin proposed that measures of discriminability and response bias could be obtained by algebraic manipulations of these two matching equations (see Davison & Tustin, 1978, for details). Discriminability ( $\log d$ ) is calculated by

$$\log d = 0.5 \log \left( \frac{B_w \cdot B_z}{B_x \cdot B_y} \right), \quad (2)$$

and response bias ( $\log b$ ) by

$$0.5 \log \left( \frac{B_w \cdot B_y}{B_x \cdot B_z} \right) = a \log \left( \frac{R_w}{R_z} \right) + \log c, \quad (3)$$

where all notation is as above.  $\log d$  is similar to traditional signal-detection measures (e.g.,  $d'$ , Green & Swets, 1966) and is functionally equivalent to Luce's choice theory measures (e.g.,  $\log \alpha$ , Luce, 1963).  $\log b$  is similar to some traditional signal-detection measures (e.g., the criterion location,  $c$ , Green & Swets, 1966) and is functionally equivalent to the choice theory measure  $\log(b)$  (Luce, 1963). Unlike these more traditional models of bias, the right side of Equation 3 stipulates which factors contribute to response bias; that is, response bias is a function of the combined effects of the obtained reinforcer ratio, sensitivity, and inherent bias, as expressed by the generalized matching law.

McCarthy and Davison (1979) tested two predictions of Davison and Tustin's (1978) behavioral account of signal detection. First, Equation 3 has no term to accommodate an influence of the relative number of  $S_1$  to  $S_2$  presentations (the stimulus presentation ratio), and instead predicts that effective response-bias manipulations result solely from changing the outcomes for choices, such as the relative reinforcement ratio. This prediction was important to test because detection experiments often produce response bias by varying the stimulus presentation ratio and rewarding every correct response. McCarthy and Davison argued that although response bias appears to be a result of the arranged stimulus presentation ratio, the obtained reinforcer ratio also tends to covary with the stimulus presentation ratio in such uncontrolled reinforcer procedures. For example, when  $S_1$  is presented more often, subjects make more  $B_1$  responses and consequently receive more reinforcers for that type of correct response. McCarthy and Davison therefore tested whether the stimulus presentation ratio or associated reinforcer ratio had a more potent influence on bias. Second, Equations 2 and 3 predict that the measures of bias and discriminability should be mutually independent, and varying response bias

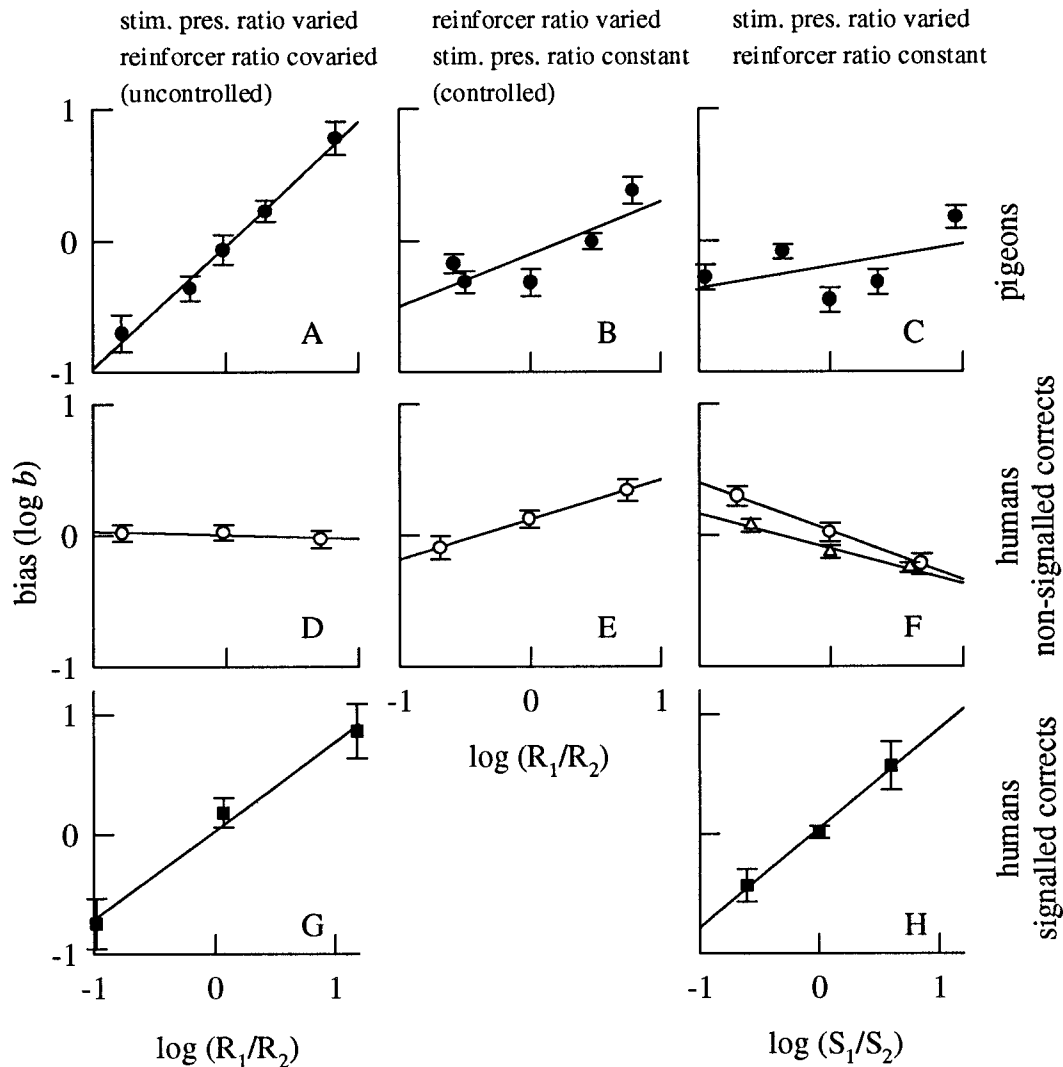


Fig. 2. The upper three panels (A, B, and C) show response bias patterns from pigeons over three different detection procedures (McCarthy & Davison, 1979). The middle three panels (D, E, and F) plot the corresponding human bias patterns over the same three procedures, in which nonreinforced but correct trials were not signaled (open circles, Alsop et al., 1995). Panel F also shows replication data from Johnstone and Alsop (1996) (open triangles). The lower two panels show human data for two of the detection procedures in which nonreinforced but correct trials were signaled (Panel G, Alsop et al., 1995; Panel H, Johnstone & Alsop, 1996).

should not be correlated with systematic changes in discriminability.

McCarthy and Davison (1979) presented pigeons with two stimuli differing in light intensity ( $S_1$  and  $S_2$ ). Left-key pecks following  $S_1$  presentations and right-key pecks following  $S_2$  presentations were occasionally reinforced. In one procedure, bias was manipulated in a manner similar to more traditional signal-detection procedures. Here, the stimulus pre-

sentation ratio was varied, and correct responses were reinforced on a single variable-ratio (VR) 3 schedule (the uncontrolled procedure). In other words, the pigeons received reinforcement after every third correct response on average, regardless of whether the correct response was associated with an  $S_1$  or  $S_2$  presentation. Figure 2A plots the obtained response bias ( $\log b$ ) against the obtained reinforcer ratio [ $\log$

( $R_1/R_2$ )] for this uncontrolled procedure. The pigeons' responses were biased towards the key associated with the most reinforcement (positive  $\log b$  values represent bias for  $B_1$  responses; negative  $\log b$  values represent bias for  $B_2$  responses). McCarthy and Davison argued that the changes in response bias for this procedure were a result of changes in the obtained reinforcer ratio rather than changes in the stimulus presentation ratio. The remaining two procedures from their study were interpreted as demonstrating this point.

In one of these procedures, the stimulus presentation ratio was held constant (at 7:3) and the reinforcer ratio was varied (termed a controlled reinforcer-ratio procedure). The pigeons' responding again showed a systematic (although smaller) bias for the more frequently reinforced response (Figure 2B). In the other procedure, however, when the stimulus presentation ratio was varied and the reinforcer ratio was held constant at 1:1, bias varied little (and perhaps not systematically) across changes in stimulus presentation ratio alone (Figure 2C). McCarthy and Davison (1979) concluded that the obtained reinforcer ratio between the two alternatives rather than variations in the stimulus presentation ratio controlled response bias. They also reported that changes in response bias were not correlated with any systematic changes in discriminability.

McCarthy and Davison (1979) interpreted their results as supportive evidence for the Davison-Tustin (1978) model of signal detection, because they showed that response bias was a function of the reinforcer ratio rather than the stimulus presentation ratio. Despite various theoretical challenges to Davison and Tustin's formulation (e.g., Alsop & Davison, 1991; Davison & Jenkins, 1985; Davison & Jones, 1995), all developments of a behavioral approach to detection are based on this premise. Thus, the McCarthy and Davison paper provides an important empirical underpinning for these models. There are however, two important reasons to reexamine McCarthy and Davison's study. First, this study contains results that seem to be inconsistent with the predictions of both the Davison-Tustin account of signal detection and other more recent behavioral models (e.g., Alsop & Davison, 1991). Second, recent work with human subjects has produced data that conflict with

McCarthy and Davison's results (Alsop, Rowley, & Fon, 1995; Johnstone & Alsop, 1996).

### *Empirical Considerations*

Two aspects of McCarthy and Davison's (1979) results warrant reexamination. First, McCarthy and Davison found that the slope of the bias function across changes in the reinforcer ratio was different for the controlled and uncontrolled procedures (Figures 2A and 2B). The average slope obtained from the uncontrolled procedure (0.95) was greater than that obtained from the controlled procedure (0.38, when the underlying  $S_1$  to  $S_2$  presentation ratio was held constant at 7:3). These slope differences are problematic because behavioral models of detection predict that the slopes across controlled and uncontrolled procedures should not differ. The slope differences found by McCarthy and Davison are in direct contrast to bias slopes obtained from controlled and uncontrolled procedures by McCarthy and Davison (1984). Here, the average bias slope obtained from the uncontrolled procedure (0.59) was lower than that obtained from the controlled procedure (0.87, when the underlying  $S_1$  to  $S_2$  presentation ratio was held constant at 1:1). A further investigation of the differences between the bias slopes obtained from controlled and uncontrolled procedures is in order.

Second, a reanalysis revealed that changes in the reinforcer ratio were correlated with systematic changes in the estimates of  $\log d$ . Figure 3 plots the mean  $\log d$  over changes in the reinforcer ratio for the uncontrolled and controlled procedures and the mean  $\log d$  over changes in the stimulus presentation ratio alone. As an overall pattern,  $\log d$  was lower when the reinforcer ratio or stimulus presentation ratio was held at 1:1 and increased as these ratios became more extreme in either direction. In order to assess whether there was a significant quadratic trend in the obtained values of  $\log d$  over changes in the reinforcer and stimulus presentation ratios, the coefficients of the linear and quadratic orthogonal polynomials were calculated for each subject in each procedure. The mean quadratic coefficient obtained from the controlled procedure was significantly different from zero: mean quadratic coefficient = 0.74,  $t(12) = 5.36$ ,  $p < .05$ . Likewise, the mean qua-

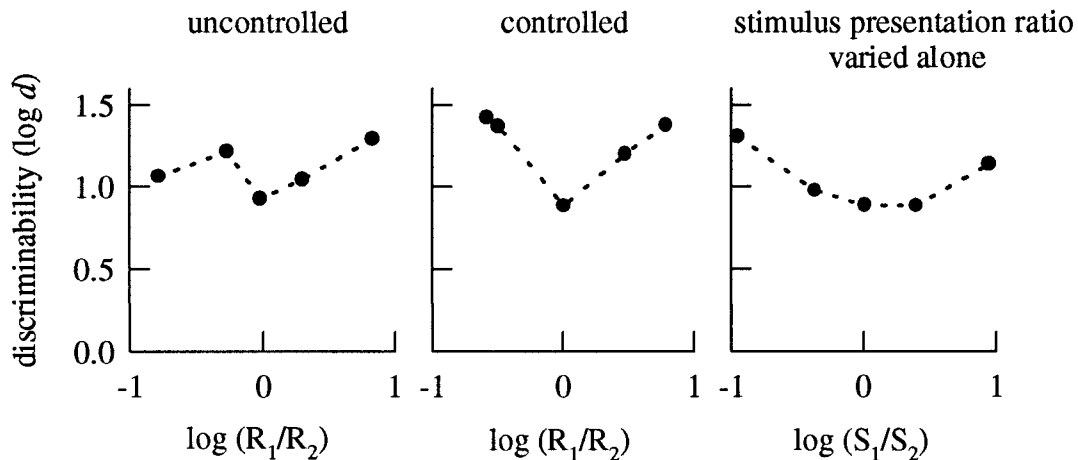


Fig. 3. Discriminability, as measured by  $\log d$ , is plotted against the  $\log$  reinforcer ratio [ $\log (R_1/R_2)$ ] for the controlled and uncontrolled reinforcer procedures, and against the  $\log$  stimulus presentation ratio [ $\log (S_1/S_2)$ ] when the stimulus presentation ratio varied alone. Data are from McCarthy and Davison (1979).

dratic coefficient from the procedure in which the stimulus presentation ratio was varied alone was also significantly different from zero:  $M = 0.38$ ,  $t(12) = 2.75$ ,  $p < .05$ . This meant that for these two procedures the estimates of  $\log d$  were lowest when the  $\log$  reinforcer ratio or the  $\log$  stimulus presentation ratio was equal to approximately zero, and increased as this ratio became more extreme. The mean quadratic coefficient obtained from the uncontrolled procedure was not significantly different from zero:  $M = 0.22$ ,  $t(12) = 1.56$ ,  $p > .05$ .

The systematic changes in  $\log d$  over changes in the reinforcer ratio and the stimulus presentation ratio are challenging for the behavioral models of detection (e.g., Alsop & Davison, 1991; Davison & Tustin, 1978). One of the aims of signal detection is to produce models that measure discriminability independent of response bias. If Davison and Tustin's model describes discriminability well, then measures of  $\log d$  should remain invariant over changes in the reinforcer and stimulus presentation ratios. Alsop and Davison's account of discriminability is also not consistent with this variation in  $\log d$ . According to this model, if discriminability is measured using  $\log d$  (Davison & Tustin, 1978), and discriminability is better explained by the Alsop and Davison account of signal detection (in terms of variations in  $d_s$  and  $d_r$ ; see Alsop & Davison, 1991), then es-

timates of  $\log d$  should be highest at the 1:1 reinforcer ratio and decrease as the reinforcer ratio becomes more extreme. Therefore, the changes in  $\log d$  over changes in the reinforcer and stimulus presentation ratios are problematic for the behavioral models of detection and also require further investigation.

#### Human Studies

Alsop et al. (1995) attempted to replicate McCarthy and Davison's (1979) findings with human subjects. As in the McCarthy and Davison study, three detection procedures were carried out: an uncontrolled and controlled reinforcer procedure and also one in which the reinforcer ratio was held constant at 1:1 and the stimulus presentation ratio was varied alone. Figure 2 (middle row of panels) shows the corresponding data from Alsop et al. There were clear differences in the patterns of response bias shown by human subjects compared with pigeons (Figure 2, upper panels) in the three procedures. The humans showed no systematic change in bias over the changes in the reinforcer ratio in the uncontrolled procedure (Figure 2D). When the reinforcer ratio was varied alone in the controlled procedure, the subjects' responses were biased towards the key associated with the most reinforcement (Figure 2E). Finally, when the stimulus presentation ratio was varied alone, the human subjects' responses were biased towards the key associated with



the stimulus presented least often (Figure 2F, open circles), a result quite different from the pigeons' performance.

Johnstone and Alsop (1996) discounted a number of procedural differences as being responsible for the differences in the patterns of response bias found by Alsop et al. (1995) and McCarthy and Davison (1979). Using human subjects, they replicated the procedure in which the stimulus presentation ratio was varied alone and found that the pattern of bias found by Alsop et al. remained intact with a different stimulus set, reinforcer value (monetary reinforcer rather than point based), and extended training (Figure 2F, open triangles).

Alsop et al. (1995) suggested that the discrepancies in performance between humans and pigeons might be due to another procedural difference, the arranged consequences for the nonreinforced but correct responses. In the McCarthy and Davison (1979) study, some correct responses (i.e., "correct reinforced responses") resulted in 3-s access to food, in addition to a 3-s display of the magazine light. Correct responses that were not reinforced with food produced only a 3-s display of the magazine light, and incorrect responses resulted in a 3-s blackout in the chamber. It is possible that the magazine light was a conditioned reinforcer for the pigeons. For example, Williams and Dunn (1991) demonstrated that when a yellow side key was consistently paired with food, the presence of the yellow side key following correct responses on nonreinforcement trials facilitated discrimination acquisition. This result indicated that the conditioned reinforcer (the yellow light) was an effective substitute for the food reinforcer. Therefore, although McCarthy and Davison claimed to be controlling the ratio of reinforcers across the keys, an uncontrolled presentation of a conditioned reinforcer could have been occurring as well. The human subjects in Alsop et al.'s (1995) experiments described thus far received no such feedback for correct but nonreinforced responses. Instead, they received exactly the same consequences for nonreinforced but correct responses and incorrect responses; that is, the screen remained blank until the next trial started.

The impact of conditioned reinforcers for the correct but non-point-rewarded trials on

human bias was investigated by Alsop et al. (1995, using a controlled procedure) and also by Johnstone and Alsop (1996, using a procedure in which the stimulus presentation ratio was varied alone). In both studies, subjects were presented with the word "correct" following all correct responses that were not scheduled for a point reinforcement. The bias patterns obtained from these two studies are plotted in Figures 2G and 2H. Both Alsop et al. and Johnstone and Alsop argued that the pattern of response bias shown by humans approximated the bias patterns shown by the pigeons when the consequences for the nonreinforced correct responses corresponded to those presented in McCarthy and Davison's (1979) study. Therefore, differences in the consequences for nonreinforced but correct responses might explain the apparent differences between the two species' behavior on these tasks. It seems logical to test this hypothesis in a more direct fashion; that is, when the potential conditioned reinforcer is removed from the procedures, the pigeons may produce response bias patterns similar to those found by Alsop et al. (1995) with humans.

The effects of the magazine light on detection have received attention in only one previous study by McCarthy and Davison (1982). They compared the discriminability and response bias patterns obtained from two uncontrolled procedures in which a magazine light was paired with all food presentations. In one procedure, the magazine light was also presented for correct responses on the nonreinforcement trials. In the other procedure, the birds received a blackout for correct responses on nonreinforcement trials (the same consequences as if the bird's response was incorrect) instead of the magazine light presentation. McCarthy and Davison concluded that there was no difference in discriminability or bias between the two procedures. A reanalysis by Alsop et al. (1995), however, found that the obtained bias did change over these procedures. When the magazine light was presented, the birds' responses were biased toward the key on which the most reinforcement was received. When the light was not presented, the birds showed no significant changes in bias across the changes in the reinforcer ratio. This result is consistent with Alsop et al.'s uncontrolled procedures in

which human subjects showed a systematic bias for the key reinforced most often when the word "correct" followed correct responses on nonreinforcement trials (Figure 2G) and no systematic bias when it did not (Figure 2D). Although McCarthy and Davison's (1982) data corroborate the idea that the procedural differences in the consequences for nonreinforced correct choices might be responsible for the different performances of humans and pigeons, conclusions based on their study must be treated with some caution due to the small sample size and possible order effects. A more systematic approach to the effects of the magazine light is necessary, especially because it has been presented for nonreinforced but correct responses in a variety of studies in the past (e.g., McCarthy, 1983; McCarthy & Davison, 1979, 1980a, 1980b, 1982, 1984).

#### *The Present Study*

Given the importance of McCarthy and Davison's (1979) results as a basis for formulations of behavioral models of detection, and given that there are several empirical issues in this paper that require clarification, a systematic replication of this study seems desirable. In addition, the effects of the magazine light signaling nonreinforced correct choices need to be examined. The current experiment reexamines bias with pigeons over the three signal-detection procedures described by McCarthy and Davison, with and without the magazine light signaling nonreinforced correct choices.

## METHOD

#### *Subjects*

Three homing pigeons (X11, X12, and X13) served as subjects. Water and grit were freely available in the home cages. Free feeding was not required because all 3 birds' weights never fell below 80% of their free-feeding maximum. All birds had prior experience with two-key concurrent schedules, and no initial training on the detection task was required.

#### *Apparatus*

The experiment was conducted in the birds' home cages (480 mm square). The

rear of each cage was fitted with an interface panel. This panel contained three response keys and a food magazine. Each response key was 25 mm in diameter. The three keys were set in a line 70 mm apart, 260 mm from the floor. The middle key could be illuminated by two white lines (3 mm wide) that differed in orientation away from upright ( $S_1$  at  $15^\circ$  or  $S_2$  at  $30^\circ$ ). The two outer keys could be illuminated either yellow, red, or green. The food magazine was located 85 mm from the floor directly below the center key and contained wheat. Neighboring birds were separated by a black partition between their cages.

#### *Procedure*

Each trial began with the center key lit with either the  $S_1$  or the  $S_2$  stimulus and the two side keys unlit. The stimulus remained on until the bird made one response to the center key. The center key was then switched off, and the two side keys were illuminated, with both either yellow, green, or red. When the bird pecked either the left or right side key, both side keylights were then switched off. Correct responses were left-key pecks following  $S_1$  presentations and right-key pecks following  $S_2$  presentations ( $B_w$  and  $B_z$  responses, respectively). Incorrect responses were right-key pecks following  $S_1$  presentations and left-key pecks following  $S_2$  presentations ( $B_x$  and  $B_y$ , respectively). Correct responses were occasionally reinforced with a 4-s presentation of the food hopper and the magazine light, or 4 s of the magazine light alone. Incorrect responses were followed by a 4-s blackout.

Six signal-detection procedures were arranged. In the first procedure, the ratio of  $S_1$  to  $S_2$  presentations was varied over three conditions (1:7.5, 1:1, and 7.5:1). Because every third correct response on average was reinforced, the reinforcer ratio could covary with the changes in the stimulus presentation ratio (an uncontrolled procedure). In the second procedure, the stimulus presentation ratio was held constant at 1:1 and the ratio of reinforcers ( $R_w$  to  $R_z$ ) was varied over three conditions (1:7.5, 1:1, and 7.5:1). These reinforcer-ratio manipulations were arranged using the following controlled procedure. A reinforcer became available according to a variable-interval (VI) 20-s schedule. Each second, the computer program that controlled the reinforcer schedule decided whether a rein-

forcer would be made available with a probability of .05 (which meant that on average, a reinforcer was made available every 20 s). This schedule ran at all times until a reinforcer became available. The timer then stopped and restarted only after the available reinforcer had been received. The computer allocated the available reinforcer to either the next  $B_w$  response or the next  $B_z$  response, according to the reinforcer ratio that was in effect for that particular condition (1:7.5, 1:1, or 7.5:1). In the third procedure, the ratio of  $S_1$  to  $S_2$  presentations was varied over three conditions (1:7.5, 1:1, and 7.5:1). The reinforcer ratio was held at approximately 1:1 for these conditions; that is, a reinforcer became available according to a VI 20-s schedule, and the computer allocated the reinforcer to either the next  $B_w$  or  $B_z$  response so that the numbers of reinforcers received for left- and right-key correct responses were approximately equal. Again, once a reinforcer was made available, the timer was stopped until this reinforcer had been received. In these three procedures, correct responses that were not scheduled for reinforcement produced a 4-s blackout; that is, the consequences for nonreinforced correct responses were identical to the consequences for the incorrect responses. The remaining three procedures were identical to those described above with one exception: All correct but nonreinforced responses were followed with the presentation of the magazine light for 4 s. The presentation order of the six detection procedures was counterbalanced across birds with the constraint that successive procedures differed in both the procedure type and whether the magazine light was present or absent for the nonreinforced correct trials.

The three conditions within each procedure (1:7.5, 1:1, and 7.5:1) were conducted in separate experimental sessions within each day. Each session consisted of 200 trials. Different colored side keylights indicated which reinforcer or stimulus presentation ratio was in effect for that session. In one session, the side keys were lit red, and the reinforcer ratio (or the stimulus presentation ratio) was 7.5:1. In another session, the side keys were lit green, and the reinforcer ratio (or the stimulus presentation ratio) was 1:1. In the remaining session, the side keys were lit yellow, and the reinforcer ratio (or the stimulus pre-

sentation ratio) was 1:7.5. The presentation order of the three conditions was randomly determined each day. In general, the first session began at approximately 9:30 a.m. (after the birds were weighed). No time limit was imposed on the completion of a particular session, and consecutive sessions were separated by 2 hr. If all sessions were not completed by approximately 9:00 a.m. the next day, the computer program that controlled the session presentation stopped and the data to date were saved. Table 1 displays the presentation order of the six detection procedures for each bird, and includes the number of sessions required for the three conditions within a procedure to reach stability. Stability criteria required assessing performance in the three reinforcer or stimulus presentation ratios per procedure simultaneously. The obtained bias in each condition for each day was plotted for each bird, and stability was assessed on performance on all three conditions. Performance was considered stable when there were no obvious changes in performance over all three reinforcement or stimulus presentation ratios. Replications of the first procedure for each bird were carried out after all six procedures had been completed. The replication conditions are also included in Table 1.

## RESULTS

The last five viable sessions from each experimental condition were analyzed for each procedure for each bird. A session was defined as viable if the bird completed more than 100 of the 200 total possible trials. Typically, the birds successfully completed all three conditions arranged over a day's running. For both X11 and X12, none of the last five sessions for any condition within a procedure needed to be discarded. For X13, a total of nine sessions (out of 105) needed to be replaced by the next most recent viable sessions for the particular condition in effect.

The number of left- and right-key responses following  $S_1$  presentations ( $B_w$  and  $B_x$ , respectively) and  $S_2$  presentations ( $B_y$  and  $B_z$ , respectively) were totaled, and the corresponding log  $d$  and log  $b$  measures were calculated. The number of reinforcers obtained for correct  $B_w$  and  $B_z$  responses was also totaled ( $R_w$  and  $R_z$ , respectively). The obtained



stimulus presentation ratios [ $\log (S_1/S_2)$ ] and reinforcer ratios [ $\log (R_1/R_2)$ ] were also calculated for each condition. Table 1 summarizes these values over changes in conditions for each procedure and each bird. For X11 and X12, the replication of the first procedure produced bias and discriminability patterns very similar to the original pattern (see Table 1). In the replication of the uncontrolled procedure in which the magazine light was absent for correct but nonreinforced responses, however, X13's discriminability was extremely poor (average  $\log d = 0.09$ ) compared to the original procedure (average  $\log d = 0.44$ ), and indeed compared to any other procedure for this bird. Key preference in this replication appeared to be primarily controlled by the reinforcer ratio alone, with no differential stimulus control. Although it remains unclear why this occurred, this poor discriminability was considered anomalous and the replication condition from X13 was dropped from any further analyses.

Figure 4 shows representative bias over the last 20 days of two successive procedures for each bird. These plots are typical of the range of bias over successive days and over successive procedures.

One initial concern with conducting three different conditions within a day was that performance might change over the course of the day. Figure 5 plots the average response bias ( $\log b$ ) for each condition when it was run as the first, second, or third daily session for each procedure. These bias values were calculated from data over the last 20 days of each procedure (to allow a reasonable number of instances of a particular condition to occur first, second, or third in a day). There were no systematic differences between the obtained bias values for a particular condition when it was run in the first, second, or third daily session. Figure 6 plots the corresponding discriminability data ( $\log d$ ) for each bird. Again, there were no systematic differences between the obtained discriminability values for a particular condition when it was run in the first, second, or third daily session.

The obtained response bias ( $\log b$ , Equation 3) for each bird was plotted as a function of changes in the reinforcer or stimulus presentation ratio for each procedure (shown in Figure 7), with and without magazine-light

presentations for the nonreinforced but correct responses. The top three panels of Figure 7 show response bias in the uncontrolled procedure, in which the reinforcer ratio was allowed to covary with the stimulus presentation ratios. As in McCarthy and Davison's (1979) results, bias changed as a function of the arranged stimulus presentation ratio and the associated obtained reinforcer ratio in this procedure. The pigeons' responding was biased towards the key associated with the stimulus presented more often and therefore reinforced more often. The middle row of panels of Figure 7 shows the corresponding results from the controlled procedure, in which the stimulus presentation ratio was held constant at 1:1 and only the reinforcer ratio was varied. Again, the pigeons' responding was biased towards the key associated with the most reinforcement. The bottom row of panels in Figure 7 shows response bias when the stimulus presentation ratio was varied and the reinforcer ratio was held constant at 1:1. A small positive slope occurred with each bird in this procedure. This meant that the birds' responses were slightly biased towards the key associated with the stimulus presented most often. This last finding is in contrast to McCarthy and Davison's report that bias did not vary as a function of changes in the stimulus presentation ratio alone. The other major feature of Figure 7 was that there were no consistent differences in bias when the magazine-light feedback was present or absent for nonreinforced correct responses for all birds over the three procedures.

The slopes obtained from each bird are presented in Figure 8, which allows a more detailed examination of the effects of the procedures and the magazine-light presentation. A  $2 \times 3$  within-subject ANOVA on the obtained slopes from Figure 7 revealed a significant effect of procedure,  $F(2, 4) = 45.57$ ,  $p < .05$ , but no significant effect of the magazine-light presentation,  $F(1, 2) = 8.05$ ,  $p > .05$ , or any significant interaction between these variables,  $F(2, 4) = 0.36$ ,  $p > .05$ . (Note that this analysis included the replication data by averaging the two slopes obtained from the original procedure and the replication for X11 and X12 to obtain one estimate of bias for each bird under these conditions.)

Further analyses revealed two major findings that were in contrast to McCarthy and

Table 1

The total number of left- and right-key responses following  $S_1$  ( $B_w$  and  $B_x$ , respectively) and  $S_2$  ( $B_y$  and  $B_z$ ) and the total number of reinforcers received for correct left- and right-key responses ( $R_w$  and  $R_z$ , respectively) are shown for the three conditions within each procedure for each bird. These values were calculated by summing the data obtained from the last five sessions for each condition within a procedure. The corresponding discriminability ( $\log d$ ), response bias ( $\log b$ ) measures, and the stimulus presentation ratio [ $\log(S_1/S_2)$ ] and reinforcer ratio [ $\log(R_1/R_2)$ ] are also shown for each condition. Procedures are listed in the order of presentation for each bird. The conditions within each procedure are listed in the order of 1:1, 7.5:1, and 1:7.5. The number of sessions required to complete a procedure is shown in parentheses in the second column. Abbreviations for the six procedures are as follows. S/R on denotes the uncontrolled procedure (in which the stimulus presentation ratio was varied and the reinforcer ratio was covaried) when the magazine light was present for nonreinforced correct responses. S/R off denotes the corresponding uncontrolled procedure when the magazine light was absent for the nonreinforced correct responses. R on and R off denote the two controlled procedures (in which the reinforcer ratio was varied and the stimulus presentation ratio was held constant) with and without the magazine light for correct nonreinforced responses, respectively. S on and S off denote the two procedures in which the stimulus presentation ratio was varied and the reinforcer ratio was held constant, with and without the magazine light for correct but nonreinforced responses, respectively.

Sub- ject	Procedure	$B_w$	$B_x$	$B_y$	$B_z$	$R_w$	$R_z$	$\log d$	$\log b$	$\log(S_1/S_2)$	$\log(R_1/R_2)$
X11	S on (39)	454	30	72	444	107	109	0.98	0.19	-0.03	-0.01
		857	23	13	107	67	64	1.24	0.33	0.87	0.02
		108	11	67	814	73	58	1.04	-0.05	-0.87	0.10
	R off (35)	420	37	84	459	126	105	0.90	0.16	-0.07	0.08
		496	5	170	329	178	33	1.14	0.85	0.00	0.73
		331	167	6	496	27	212	1.11	-0.81	0.00	-0.89
	S/R on (74)	406	94	33	467	129	156	0.89	-0.26	0.00	-0.08
		874	8	26	92	324	29	1.29	0.74	0.87	1.05
		81	41	7	871	25	305	1.20	-0.90	-0.86	-1.09
	S off (63)	470	21	66	443	107	124	1.09	0.26	-0.02	-0.06
		812	54	30	104	54	59	0.86	0.32	0.81	-0.04
		125	18	71	786	68	84	0.94	-0.10	-0.78	-0.09
	R on (63)	406	70	78	446	122	101	0.76	0.00	-0.04	0.08
		470	23	232	275	217	26	0.69	0.62	-0.01	0.92
		251	278	9	462	39	208	0.83	-0.88	0.05	-0.73
	S/R off (68)	404	104	30	462	145	153	0.89	-0.30	0.01	-0.02
		850	12	57	81	280	23	1.00	0.85	0.80	1.09
		58	61	4	877	20	306	1.16	-1.18	-0.87	-1.18
	S on (72)	472	36	113	379	103	92	0.82	0.30	0.01	0.05
		704	170	31	95	60	68	0.55	0.07	0.84	-0.05
		99	28	150	723	71	61	0.62	-0.07	-0.84	0.07
X12	R off (53)	319	223	69	389	99	102	0.45	-0.30	0.07	-0.01
		495	6	311	188	197	29	0.85	1.07	0.00	0.83
		131	374	7	488	24	185	0.69	-1.15	0.01	-0.89
	S on (59)	451	30	29	490	119	122	1.20	-0.03	-0.03	-0.01
		836	27	25	112	97	73	1.07	0.42	0.80	0.12
		114	6	108	772	71	75	1.07	0.21	-0.87	-0.02
	S/R off (45)	298	163	20	519	102	172	0.84	-0.58	-0.07	-0.23
		858	14	57	71	299	23	0.94	0.85	0.83	1.11
		60	55	1	884	25	283	1.49	-1.45	-0.89	-1.05
	R on (35)	420	66	44	470	117	120	0.92	-0.11	-0.02	-0.01
		492	6	179	323	233	31	1.09	0.83	0.00	0.88
		256	226	6	512	44	197	0.99	-0.94	-0.03	-0.65
	S off (58)	386	110	39	465	116	91	0.81	-0.27	-0.01	0.11
		614	255	18	113	60	70	0.59	-0.21	0.82	-0.07
		116	28	29	827	79	57	1.04	-0.42	-0.77	0.14
	S/R on (68)	365	136	36	463	120	158	0.77	-0.34	0.00	-0.12
		857	8	74	61	284	18	0.97	1.06	0.81	1.20
		75	48	10	867	22	287	1.07	-0.87	-0.85	-1.12
	R off (54)	383	136	53	428	113	114	0.68	-0.23	0.03	0.00
		487	7	239	267	214	28	0.95	0.90	-0.01	0.88
		194	307	3	496	26	199	1.01	-1.21	0.00	-0.88

Table 1  
(Continued)

Sub- ject	Procedure	$B_w$	$B_x$	$B_y$	$B_z$	$R_w$	$R_z$	$\log d$	$\log b$	$\log(S_1/S_2)$	$\log(R_1/R_2)$
X13	S/R on (42)	375	48	165	270	142	83	0.55	0.34	-0.01	0.23
		836	1	145	1	258	1	0.38	2.54	0.76	2.41
		1	153	1	846	1	319	0.37	-2.56	-0.74	-2.50
	S off (74)	419	71	43	467	104	122	0.90	-0.13	-0.02	-0.07
		815	35	23	127	84	83	1.05	0.31	0.75	0.01
		128	18	22	832	82	73	1.21	-0.36	-0.77	0.05
	R on (42)	415	89	48	448	105	107	0.82	-0.15	0.01	-0.01
		498	10	94	398	201	33	1.16	0.54	0.01	0.78
		380	137	1	482	24	223	1.56	-1.12	0.03	-0.97
	S/R off (55)	392	67	26	396	145	141	0.97	-0.21	0.04	0.01
		824	21	53	79	280	21	0.88	0.71	0.81	1.12
		113	25	13	849	35	278	1.24	-0.58	-0.80	-0.90
	S on (64)	405	63	34	453	138	161	0.97	-0.16	-0.02	-0.07
		720	60	13	125	82	70	1.03	0.05	0.75	0.07
		122	18	93	733	73	85	0.86	-0.03	-0.77	-0.07
	R off (49)	433	76	60	424	155	141	0.80	-0.05	0.02	0.04
		405	14	243	201	233	37	0.69	0.77	-0.03	0.80
		324	188	14	474	33	228	0.88	-0.65	0.02	-0.84
	S/R on (96)	22	454	21	417	6	135	-0.01	-1.31	0.04	-1.35
		866	12	120	2	294	1	0.04	1.82	0.86	2.47
		4	112	11	873	1	277	0.23	-1.67	-0.88	-2.44

Davison's (1979) results. First, a paired  $t$  test revealed that the slopes from the controlled procedure (average slope = 1.02) were significantly steeper than those obtained in the uncontrolled procedure (average slope = 0.85),  $t(5) = 5.15$ ,  $p < .05$ . The two slopes obtained from the controlled procedure in which the magazine light was absent for X12 were averaged to allow this paired sample comparison. Second, slopes obtained from the procedure in which the stimulus presentation ratio was varied and the reinforcer ratio was held constant at 1:1 were significantly larger than zero (mean slope = 0.19, with a 95% confidence interval of  $\pm 0.13$ ).

Figure 9 plots the obtained  $\log d$  for each bird over changes in the reinforcer or stimulus presentation ratio for each procedure (conditions with magazine light and no magazine light from the same procedure are plotted on the same graph). In order to assess the form of the changes in  $\log d$  across the bias manipulations, the coefficients for the linear and quadratic orthogonal polynomials were calculated for each subject in each procedure. Changes in the reinforcer ratio in the controlled procedure were correlated with discriminability changes consistent with those found in the reanalysis of the controlled pro-

cedure from McCarthy and Davison (1979), as shown in Figure 3 here. The mean quadratic coefficient obtained from the controlled procedure was significantly different from zero (mean quadratic coefficient = 0.29),  $t(17) = 3.30$ ,  $p < .05$ . This meant that the estimates of  $\log d$  were lowest when the reinforcer ratio was 1:1, and increased as the reinforcer ratio became more extreme in either direction. The mean quadratic coefficient obtained from the uncontrolled procedure was not significantly different from zero (mean quadratic coefficient = 0.19),  $t(17) = 2.10$ ,  $p > .05$ . Likewise, the mean quadratic coefficient obtained from the stimulus presentation ratio varied alone was also not significantly different from zero (mean quadratic coefficient = -0.03),  $t(17) = -0.37$ ,  $p > .05$ .

## DISCUSSION

Three findings from the present experiment raise issues for behavioral models of detection (e.g., Alsop & Davison, 1991; Davison & Jenkins, 1985; Davison & Jones, 1995; Davison & Tustin, 1978; Nevin, Jenkins, Whittaker, & Yarensky, 1982). First, the obtained bias slopes from the controlled procedure

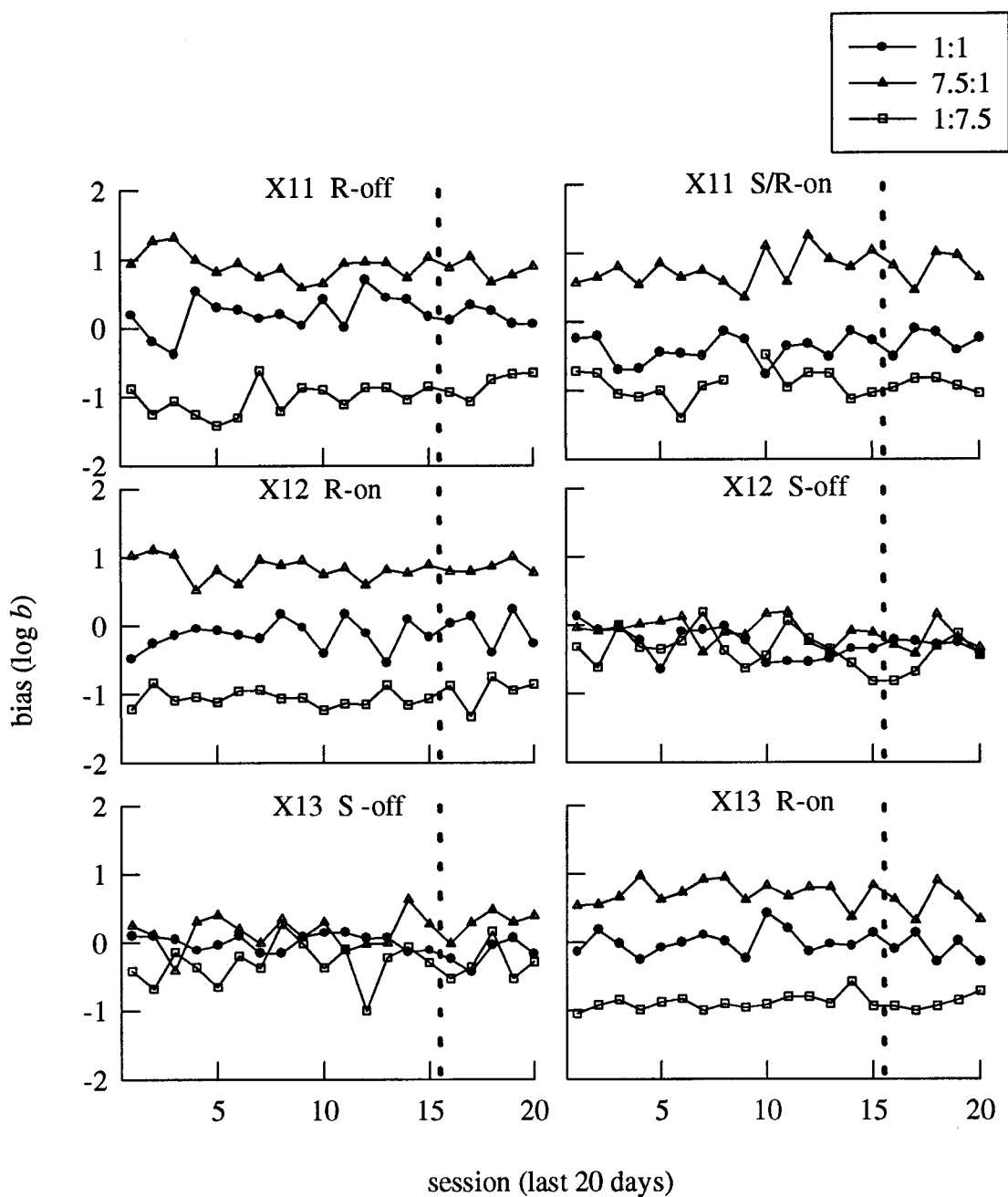


Fig. 4. Estimates of bias over the last 20 sessions, plotted for two consecutive procedures, for X11 (top panels), X12 (middle panels), and X13 (lower panels). Data obtained after the dotted vertical lines were used in the analysis. Abbreviations are defined in Table 1.

were steeper than those from the uncontrolled procedure. All behavioral models predict that the reinforcer ratio is the major contributor to response bias, and the manner in

which different reinforcer ratios are produced should have no impact on the sensitivity of subjects' behavior to these ratios; that is, the slopes of the bias functions from con-

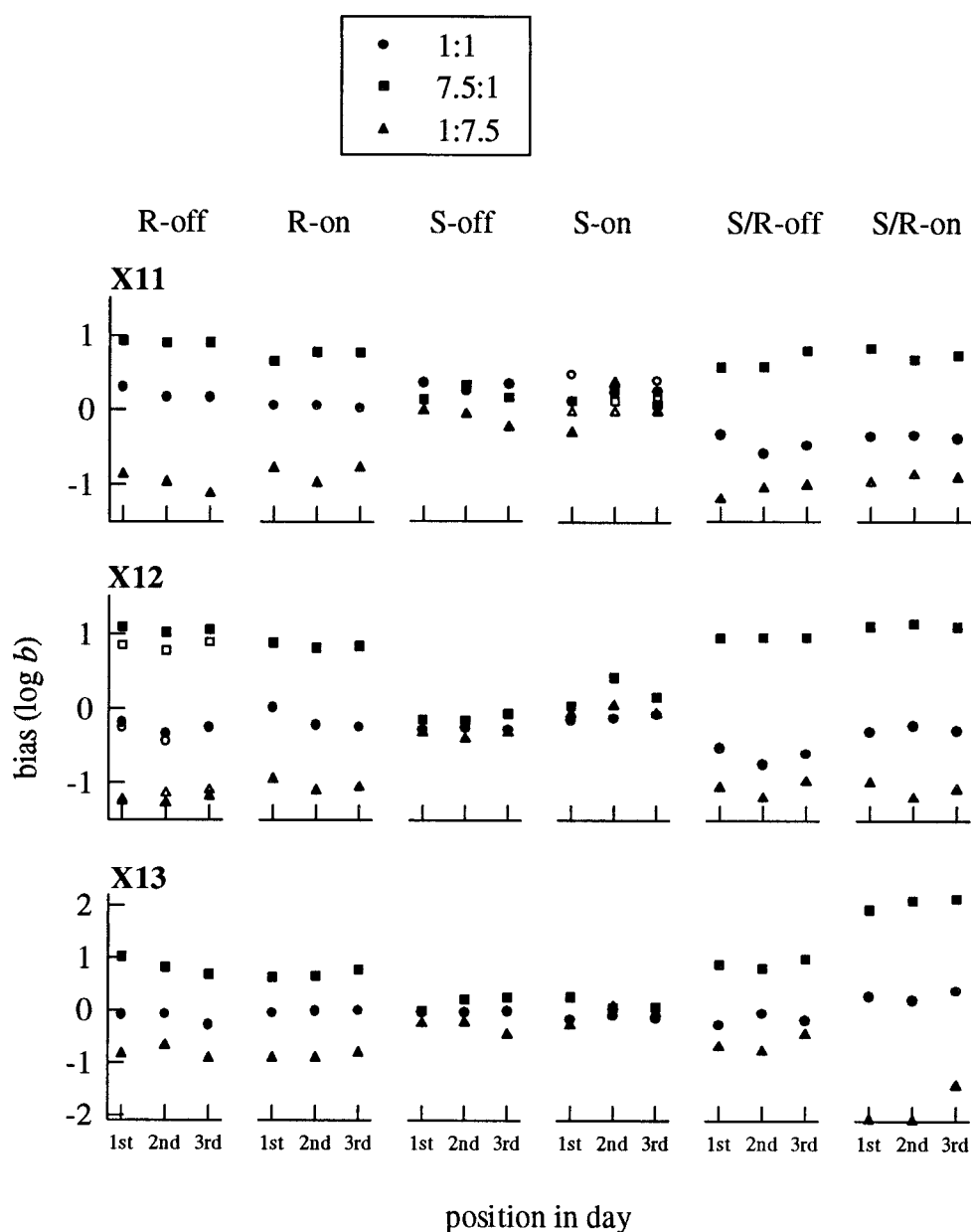


Fig. 5. Average response bias ( $\log b$ ) obtained for each reinforcer or stimulus presentation ratio within each procedure when it was the first, second, or third session within the day for X11 (top panels), X12 (middle panels), and X13 (lower panels). Replication conditions are shown as open symbols. Abbreviations are defined in Table 1.

trolled and uncontrolled reinforcer procedures should not differ systematically. The slope differences found between the controlled and uncontrolled procedures in the current study are consistent with McCarthy and Davison's (1984) results, where the slopes from the controlled procedure were

greater than those obtained from the uncontrolled procedure. The situation is complicated by McCarthy and Davison's (1979) opposite finding that bias slopes tended to be steeper for the uncontrolled procedure than for the controlled procedure. The lack of a mechanism to explain the variations in the



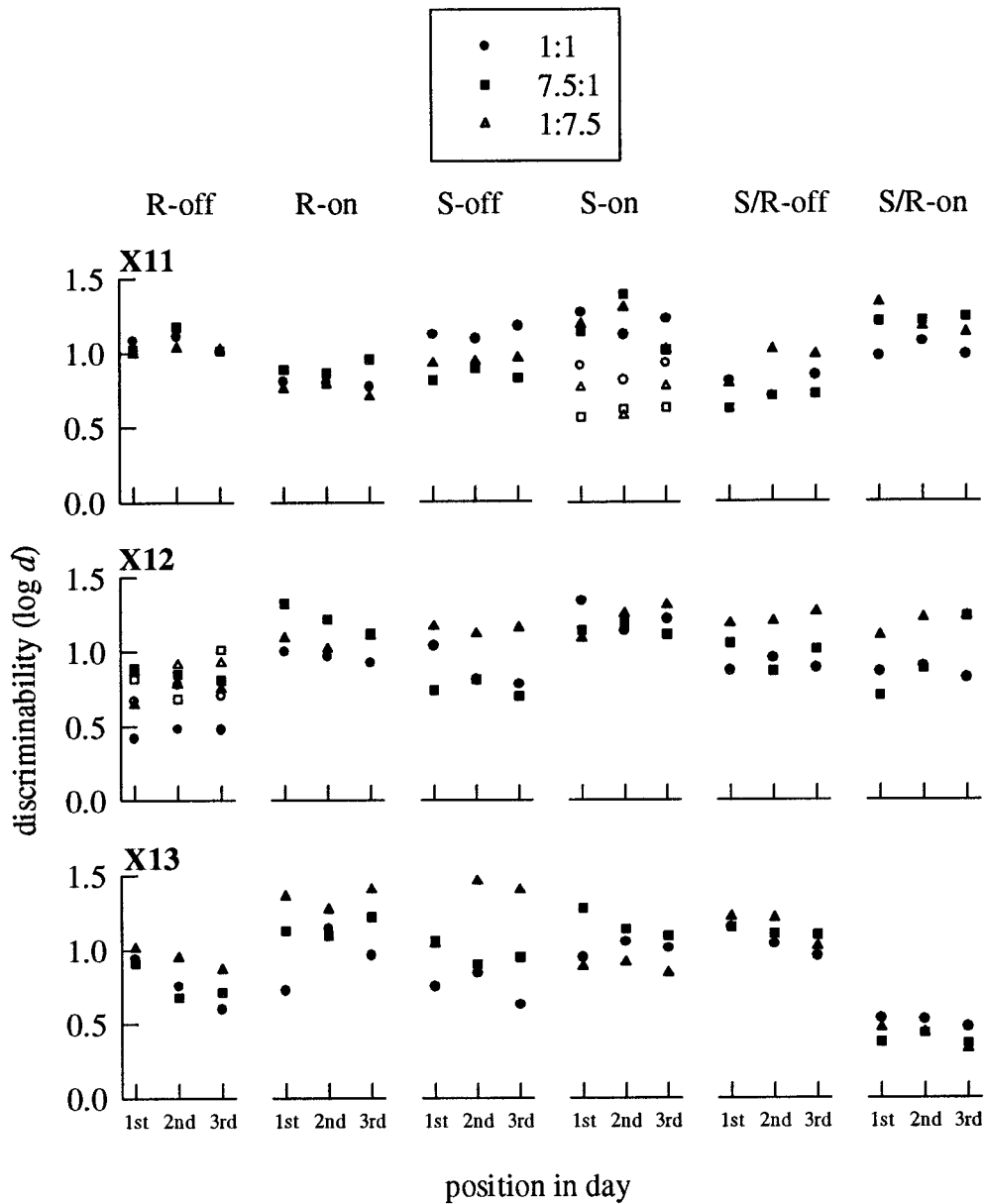


Fig. 6. Average discriminability ( $\log d$ ) obtained for each reinforcer or stimulus presentation ratio within each procedure when it was the first, second, or third session within the day for X11 (top panels), X12 (middle panels), and X13 (lower panels). Replication conditions are shown as open symbols. Abbreviations are defined in Table 1.

sensitivities obtained for the controlled and uncontrolled procedures is a weakness of current behavioral detection models.

Second, the present experiment found a small but significant bias for all birds in responding toward the key associated with the stimulus presented most often, when the stimulus presentation ratio was varied alone

(Figure 7, lower panels). This result contrasts with McCarthy and Davison's (1979) report that the pigeons' responding was not biased systematically by changes in the stimulus presentation ratio alone. Figure 10 plots the mean bias obtained across changes in the arranged stimulus presentation ratio (when the reinforcer ratio was held constant at 1:1)

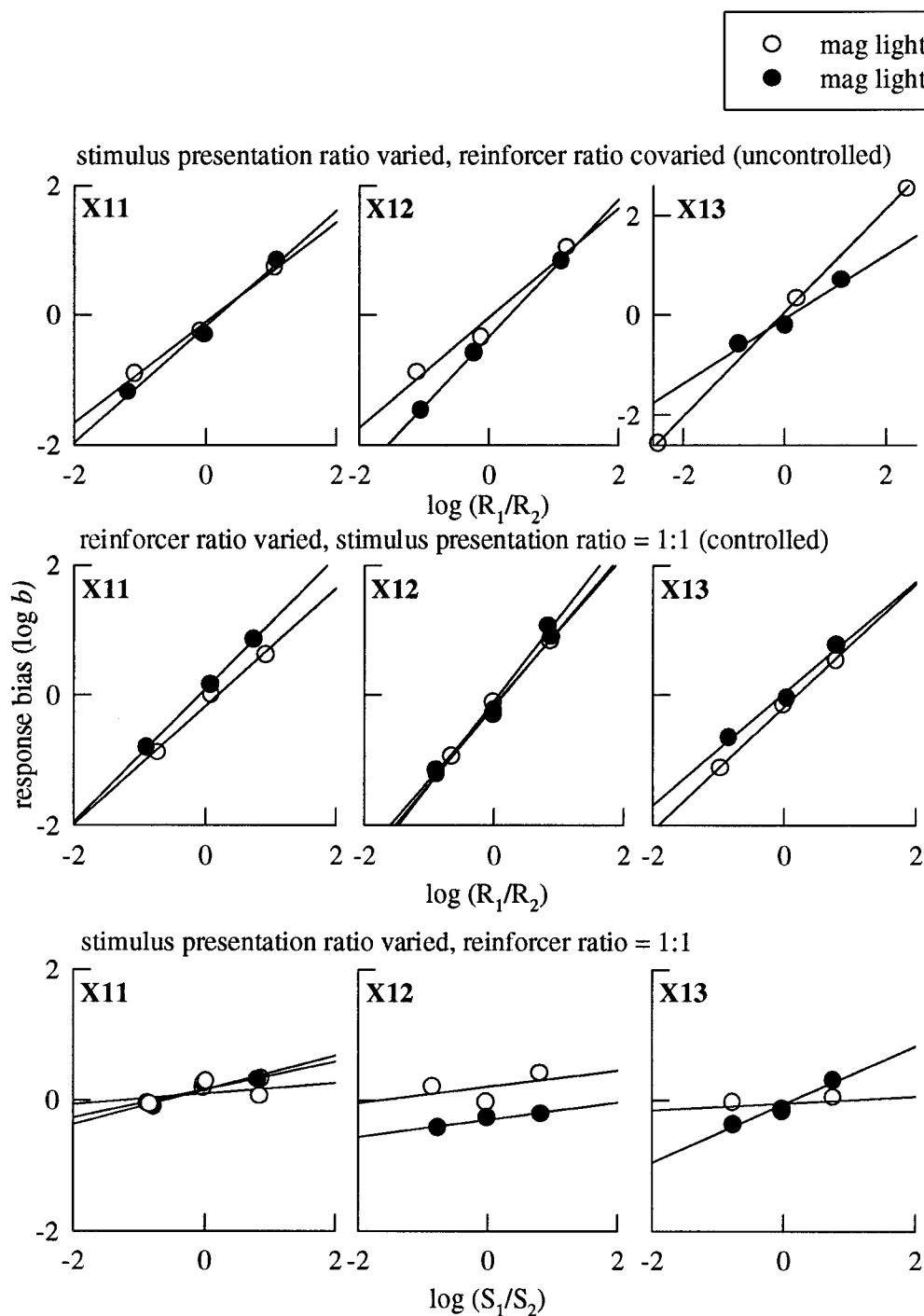


Fig. 7. Bias plotted against either the obtained reinforcer ratio or the obtained stimulus presentation ratio for the three procedures for each bird, with the magazine light present (open symbols) and absent (filled symbols) for nonreinforced but correct responses.

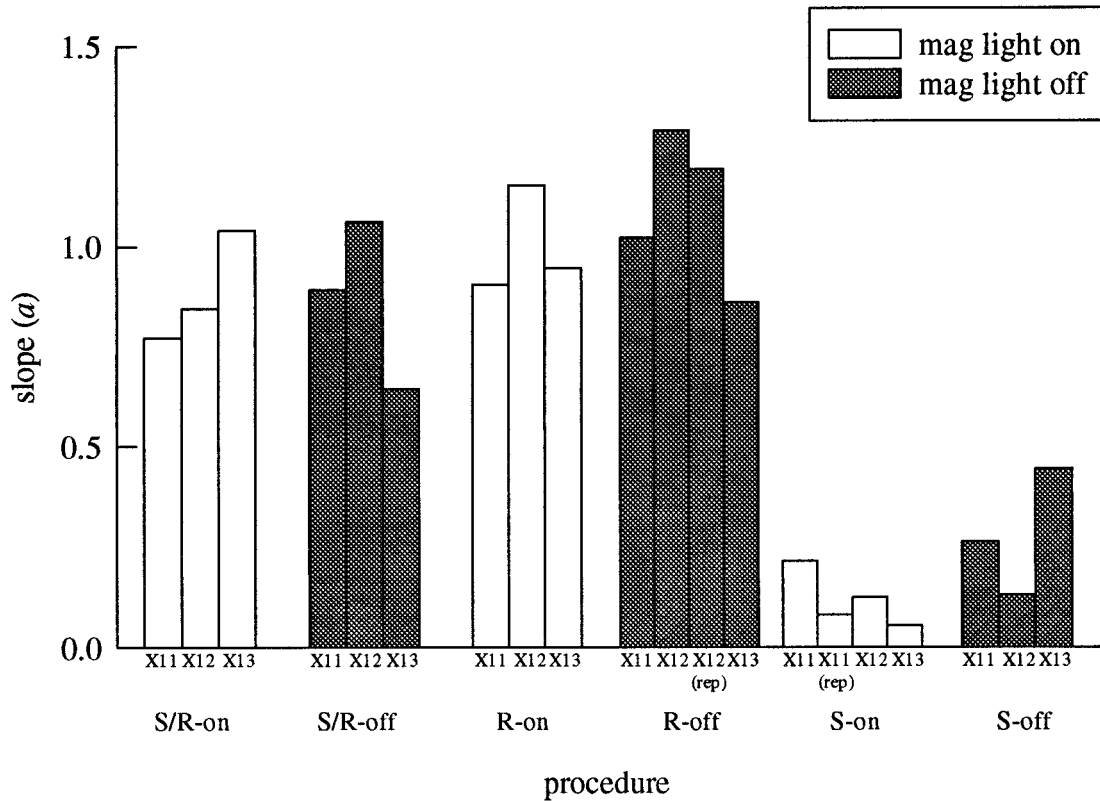


Fig. 8. Obtained bias slopes from each bird (shown in Figure 7) for the uncontrolled procedures with the magazine light present (S/R on) and absent (S/R off) for nonreinforced correct responses, the controlled procedures with the magazine light present (R on) and absent (R off) for nonreinforced correct responses, and procedures in which the stimulus presentation ratio was varied alone, with the magazine light present (S on) and absent (S off) for nonreinforced correct responses.

from the current study and from McCarthy and Davison's study. Figure 10 permits an easy direct comparison of the effects of the stimulus presentation ratio alone on response bias from these two studies. Taken together, the response bias patterns from these two studies suggest that it is difficult to dismiss the role of the stimulus presentation ratio as a biaser of a pigeon's performance. The effect of the stimulus presentation ratios on response bias is problematic for behavioral models of detection. All the models imply that the obtained reinforcer ratio is the primary contributor to response bias (e.g., Equation 3), and none allow any role of the stimulus presentation ratio as a determinant of response bias. The findings from the current study indicate that the stimulus presentation ratio produced some bias (albeit small) which

remains unexplained by the behavioral detection models.

Third, the current experiment produced results that were compatible with the significant changes in  $\log d$  over variations in the bias manipulations found in the McCarthy and Davison (1979) study; that is, the current study found that estimates of  $\log d$  were lower when the log reinforcer ratio was held at 1:1 and increased as the log reinforcer ratio became more extreme in either direction for the controlled procedure. Given that these  $\log d$  effects were small, it seemed worthwhile to examine whether they were consistent with the reanalysis of a number of other studies. In the current study and that by McCarthy and Davison, the largest and most consistent  $\log d$  changes occurred when the reinforcer ratio was varied using a controlled procedure.

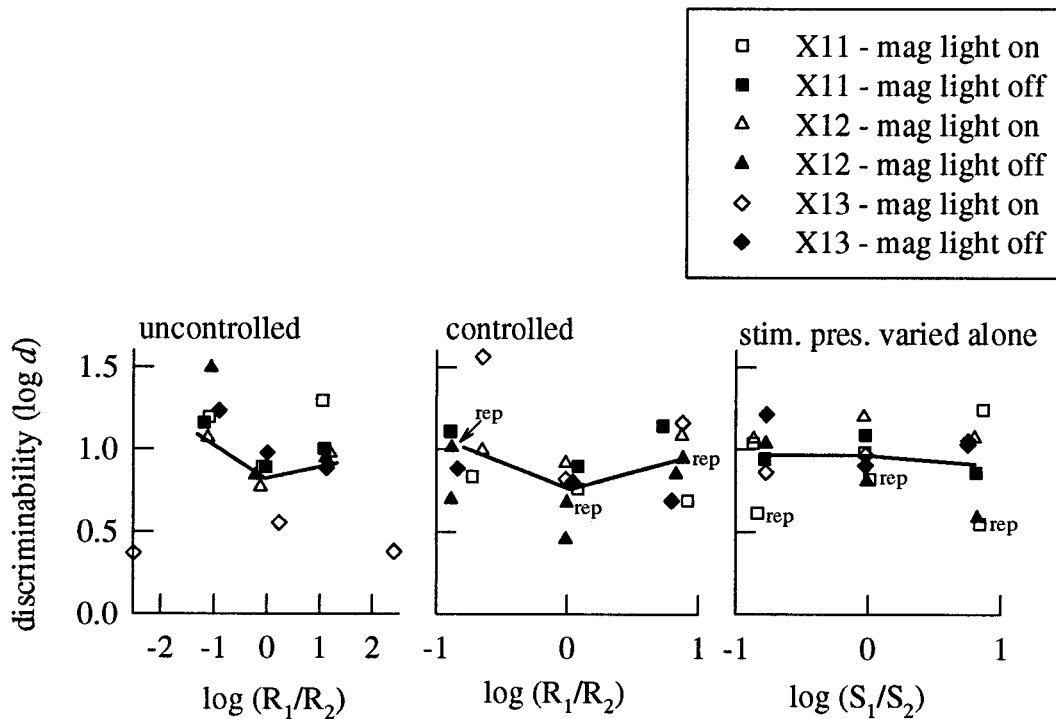


Fig. 9. The obtained  $\log d$  measures for each bird over changes in the log reinforcer ratio for the uncontrolled procedure and controlled procedure and over changes in the log stimulus presentation ratio when the stimulus presentation ratio varied alone. Filled and open symbols indicate the conditions in which the magazine light was present and absent for nonreinforced correct responses, respectively.

Therefore, the  $\log d$  measures from three other studies that employed controlled procedures were also examined. Figure 11 plots the obtained  $\log d$  measures from the controlled procedures of the current study and that of McCarthy and Davison along with the  $\log d$  measures from controlled procedures conducted by Nevin et al. (1982), McCarthy and Davison (1984), and Alsop and Davison (1991) against the obtained log reinforcer ratio. The  $\log d$  values were calculated from the conditions in which the reinforcer ratio was held at 1:1 and from the two conditions in which the reinforcer ratio was the most extreme in each study. In the McCarthy and Davison (1984) and Alsop and Davison (1991) studies, discriminability varied over the reinforcer conditions. Only the data from the conditions in which subjects showed  $\log d$  measures greater than 0.2 were included in this figure, because when discriminability is low, the predicted isosensitivity functions of the competing signal-detection models (e.g., Alsop & Davison, 1991; Davison & Tustin,

1978; Green & Swets, 1966; Luce, 1963) become increasingly similar and are uninformative.

Figure 11 shows a mixed pattern of the obtained  $\log d$  values across changes in the reinforcer ratio. Most studies show higher estimates of  $\log d$  at the unequal reinforcer ratios than when the reinforcer ratio is held at 1:1 (e.g., the current study; McCarthy & Davison, 1979, 1984; and three of the four discriminability conditions from Alsop & Davison, 1991). The  $\log d$  estimates from the remaining studies, however, do not show this pattern. Instead,  $\log d$  tends to increase with increases in the reinforcer ratio (e.g., Nevin et al., 1982, and the remaining discriminability condition from Alsop & Davison, 1991). Although some variability in  $\log d$  across changes in the reinforcer ratio over the different studies is expected, Figure 11 indicates that this variation might be systematic; that is, in 8 of the 10 cases the  $\log d$  estimates are lowest when the reinforcer ratio is held at 1:1.

It is possible that some of the higher  $\log d$

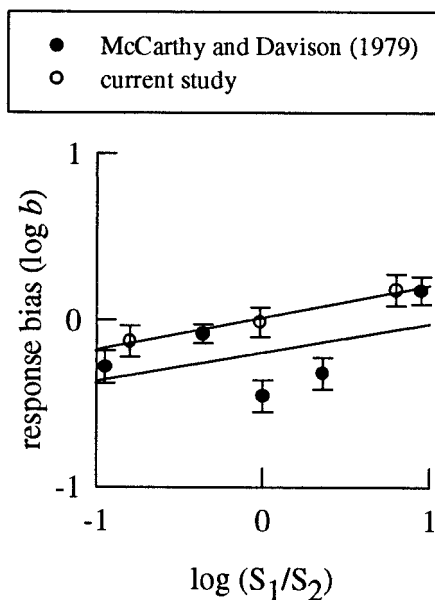


Fig. 10. The average response bias ( $\log b$ ) obtained when the stimulus presentation ratio was varied alone is plotted over changes in the stimulus presentation ratio. The filled circles show obtained average bias from Davison and McCarthy (1979). The open circles show the corresponding data from the current study.

estimates at the unequal reinforcer-ratio conditions shown in Figure 11 are the result of the presentation order of conditions. In some of the studies shown in Figure 11 (most notably McCarthy & Davison, 1984), the more extreme reinforcer-ratio conditions were completed after the 1:1 reinforcer-ratio condition at each discriminability level. Therefore, the higher estimates of  $\log d$  at the more extreme reinforcer ratios for these studies could be the result of the pigeons' increased familiarity with the particular stimulus set. Although this is possible, other studies find higher estimates of  $\log d$  at the more extreme reinforcer ratios when this procedural confounding effect is less likely to be implicated (e.g., the current experiment; McCarthy & Davison, 1979). It is crucial for future research to clarify whether  $\log d$  estimates change systematically over changes in the reinforcer ratio, given that the pattern of  $\log d$  implied by Figure 11 is problematic for the behavioral models of detection. The Davison and Tustin (1978) model predicts that  $\log d$  should provide a constant measure of discriminability when the reinforcer ratio is var-

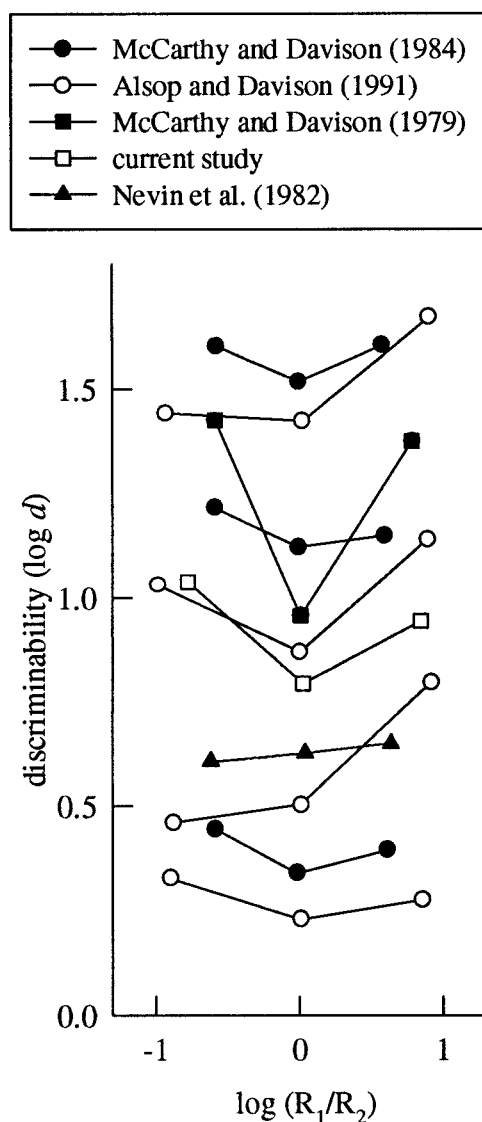


Fig. 11. The obtained  $\log d$  measures over variations in the reinforcer ratio from five studies. Variations in the reinforcer ratio were produced using controlled reinforcer procedures.

ied; that is,  $\log d$  should not vary systematically as a function of the reinforcer ratio. If performance is best described by the Alsop and Davison (1991) model, measures of  $\log d$  should be the greatest when the reinforcement across alternatives is equal and should decrease as the reinforcer ratio becomes more extreme.

It is also important to note that the ratio of  $S_1$  to  $S_2$  presentation was held at 7:3 in the



McCarthy and Davison (1979) controlled procedure. This ratio was held at 1:1 for all the other studies shown in Figure 11. The McCarthy and Davison (1979) controlled procedure is also associated with the most dramatic differences in  $\log d$  between equal and unequal reinforcement across alternatives (see Figure 11). It is unclear whether this larger change in  $\log d$  is a function of the differences in the ratio of  $S_1$  to  $S_2$  presentations arranged in that study. Therefore, it is also probably necessary for future research to examine whether the underlying stimulus presentation ratio is implicated in any changes in  $\log d$  over changes in the reinforcer ratio.

The current study arranged a different procedure than the McCarthy and Davison (1979) study. In the current study, the three different reinforcer or stimulus presentation conditions were run in consecutive sessions each day, whereas in the McCarthy and Davison study, each reinforcer (or stimulus presentation) condition was completed over successive sessions. There is no evidence that this procedural change compromised the results of the current experiment, for three reasons. First, the obtained  $\log b$  and  $\log d$  measures for a particular condition did not vary as a function of whether the condition was conducted in the first, second, or third session within a day (see Figures 5 and 6). The stability of the performances across the three daily session positions indicated that performance in the different conditions seemed to be independent of and unaffected by factors associated with time of day.

Second, there was good differential control of choice by the reinforcer ratios even though the three different reinforcer ratios (within a procedure) were conducted each day, as evidenced by the obtained bias slopes from the controlled and uncontrolled procedures (1.02 and 0.85, respectively). These slopes are comparable to those generally found in matching law research in which the reinforcer conditions within a procedure are run individually to stability both with standard concurrent schedules (range, 0.7 to 0.9; Davison & McCarthy, 1988) and with detection experiments. For example, controlled procedures from Stubbs (1976), Nevin et al. (1982), and McCarthy and Davison (1979, 1984) produced slopes of 0.71, 0.90, 0.34, and 0.87, re-

spectively. Uncontrolled procedures from McCarthy and Davison (1979, 1984) and Davison and Jenkins (1985) produced slopes of 0.95, 0.59, and 0.56, respectively. The good differential control obtained in the current procedure resembles that found in similar procedures (in which different contingencies are arranged consecutively and are signaled by discriminative stimuli) with concurrent chains (e.g., Grace, 1995) and with single VI schedules (e.g., Heyman & Monaghan, 1994).

Finally, the results of the current study have precedents in other behavioral detection studies that use the more conventional condition arrangement (e.g., McCarthy & Davison, 1979, 1984). The current study found that changes in the reinforcer ratio in the controlled procedure were correlated with systematic changes in  $\log d$  (Figure 9, middle panel), a finding consistent with the reanalysis of McCarthy and Davison's (1979) results (Figure 3, middle panel). The differences in the obtained slopes from the controlled and uncontrolled procedures are consistent with those found by McCarthy and Davison (1984). In addition, the current study showed bias patterns similar to those obtained by McCarthy and Davison (1979) when the stimulus presentation ratio was varied alone (see Figure 10). Therefore, the current experiment did not produce any results that were extremely unusual or incompatible with those obtained in previous behavioral detection experiments in which each condition was completed separately.

The present study does not resolve the issue of why pigeons and humans performed differently on the signal-detection tasks reported by McCarthy and Davison (1979), Alsop et al. (1995), and Johnstone and Alsop (1996). There were no significant effects of the magazine light on bias and discriminability, so this factor does not appear to be responsible for the differences between pigeons and humans on these detection tasks. When the magazine light was absent, the bias shown by the pigeons did not approximate the patterns of bias shown by Alsop et al. (1995) with humans.

At this point it seems necessary to reconsider the source of the discrepancies in bias reported by Alsop et al. (1995) with humans and by McCarthy and Davison (1979) with pigeons. The current study and that of John-

stone and Alsop (1996) have largely ruled out a variety of procedural factors (i.e., magazine-light effects, amount of training, and reinforcer type). Investigating explanations other than these procedural differences may be more profitable. For example, humans' and pigeons' performance may be influenced differently by the specific signal-detection outcomes. Alsop et al. (1995) suggested that nonreinforced trials may be punishing to human subjects but not to pigeons, due to different reinforcement histories; that is, a lack of feedback for humans is generally associated with being incorrect rather than correct, whereas pigeons probably have no such history. Investigations along these lines have been limited to a few experiments (Johnstone & Alsop, 1996). Indeed, Macmillan and Creelman (1990, 1991) noted a lack of systematic studies in recent reviews of human signal detection. Future research might explore further the factors that influence bias in humans. For example, why is human performance biased towards the stimulus presented least often when the reinforcement across alternatives is held equal, as described by Alsop et al. (1995) and Johnstone and Alsop (1996)? The conflicting data within the nonhuman animal literature and between the human and nonhuman animal subjects suggest that the sources of response bias may not be as well understood as is generally assumed. Before a detection model can be successful, a clarification of what factors produce and influence bias in both human and animal populations is required.

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Received May 18, 1998

Final acceptance February 10, 1999